ANALYSIS OF FRACTURED TEETH UTILIZING DIGITAL MICROSCOPY:

A PILOT STUDY

by

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A thesis submitted to the Faculty of the
Endodontic Graduate Program
Naval Postgraduate Dental School
Uniformed Services University of the Health Sciences
in partial fulfillment of the requirements for the degree of
Master of Science
in Oral Biology

June 2016

Naval Postgraduate Dental School

Uniformed Services University of the Health Sciences
Bethesda, Maryland

CERTIFICATE OF APPROVAL

MASTER'S THESIS

This is to certify that the Master's thesis of

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2016

ABSTRACT

ANALYSIS OF FRACTURED TEETH UTILIZING DIGITAL MICROSCOPY: A PILOT STUDY

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Introduction: The detection of vertical fractures in teeth can be diagnostically challenging for clinicians. Signs and symptoms associated with fractured teeth can mimic those associated with diseased pulps as well as symptomatic teeth with previous endodontic treatment, compounding the diagnostic difficulty. The application of high-resolution 3D Cone Beam Computed Tomography (CBCT) imaging in detecting vertical root fractures has generated considerable interest. Multiple studies have measured fractures in extracted human teeth, utilizing various methodologies, to correlate the size of the fracture necessary for radiographic detection. However, digital microscopy has not been utilized to measure fractures in extracted human teeth. **Purpose:** This pilot study explored various techniques for measuring fractures in extracted human teeth with a digital microscope (Hirox KH-7700, Digital Microscope and software). **Methods**: Three mandibular and two maxillary human teeth were evaluated for fractures utilizing different optics and lighting conditions, as well as various tooth and microscope positions. **Results**: Rope wax facilitated stabilization and positioning of the fracture. The optimal image was identified when using a Revolver Zoom Lens and a co-axial lighting supplemented by an external light source. Positioning the microscope 5-15° off the perpendicular axis minimized light reflection. A 200-250x magnification produced a visual field supporting samples for imaging in three regions; coronal, middle, and apical. Using the line measurement tool in 2D, three fracture widths were recorded in each region with a resolution of $1.0x10^{-6}$mm. Data were gathered and reviewed to ensure reproducible measurements could be obtained utilizing this methodology. **Conclusion**: The Hirox KH-7700 Digital microscope and software demonstrated the ability to reliably measure fractures in human extracted teeth. A

follow on study will utilize this methodology to assess the relationship between fracture width and the ability to detect fractures using limited field of view CBCT imaging.

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I. INTRODUCTION

A fractured tooth is a challenging dental condition that potentially involves the need for endodontic treatment. The detection of a vertical root fracture usually presents as a diagnostic problem for clinicians. Cohen et al. noted vertical root fractures to be most prevalent in the maxillary premolars (23%), mandibular first molars (21.59%) and mandibular second molars (21.15%) (1). Pulp necrosis is suspected in the majority of cases due to an undiagnosed longitudinal fracture extending into the pulp canal system. A common presentation is pain upon biting and cold sensitivity associated with the offending tooth. Description of symptoms for a fractured tooth are typically characterized by a sharp, brief pain occurring unexpectedly while occluding, which can be triggered or exacerbated by tooth-to-tooth contact. The stimulus that elicits pain in a fractured tooth is often obscure and difficult to reproduce in the dental chair.

The type and consistency of pain may elicit a number of different responses. Pain may be spontaneous, sharp or dull and occur consistently or be intermittent. There may be periods of exaggerated pain or quiescence. Patients may alter habits to avoid the pain and thus delay treatment. These types of fractures are often confined to the dentin without invasion of the pupal/dentin complex. The sharp pain is possibly generated from alteration in the odontoblastic process near the fracture site. Multiple tests are utilized when attempting to identify a vertical fracture**,** often with inconclusive results (1).

As with other materials, glass, concrete or ceramics, cracks propagate in dentin and increase in length and width. As fractures propagate, their impingement on the pulp causes an increase in intensity of symptoms and ultimately the pulp becomes irreversibly inflamed. Delayed management allows bacteria to migrate and invade the pulp space resulting in an irreversible status. Testori et al. stated that the average time for diagnosis of a VRF is 10.8 years (2). Once a diagnosis is established, the prognosis for a tooth with a VRF is unfavorable, as there are currently no reliable treatment methods. The affected tooth is deemed non restorable and extraction is necessary (3). In this context, a reliable diagnosis of VRF is critical to prevent unnecessary extraction of an otherwise treatable tooth.

A fracture in a tooth is difficult to discern radiographically as the fracture generally lies parallel to the sensor hindering visualization in a two dimensional image. All radiographic

systems have limitations for accurate detection of root fractures. With the use of two-dimensional conventional or digital radiography, fractures are more likely to be missed if the primary X-ray beam is not within 4 degrees of the fracture plane (4). Compounding the situation is the superimposition of surrounding anatomic structures, which hinders identification of pathosis (5). Horizontal or buccolingual fractures are easy to demonstrate radiographically, however a mesial/distal fracture is challenging to discern with two-dimensional radiography and limited with three-dimensional radiography.

Brynolf noted the overall diagnostic accuracy of two-dimensional radiography was improved by taking straight and angled radiographs, suggesting 78% accuracy with one radiograph and 92% accuracy using three radiographs (6). Tamse described some radiographic features that are suggestive of vertically fractured endodontically treated teeth to include a “halo” or “J” shaped lesion and to be a significant finding in 63.3% of cases (7). Two-dimensional radiograph does not possess the accuracy needed to adequately diagnosis fractures.

Cone beam computed tomography (CBCT) is a more recent advanced imaging modality that was introduced in the United States in 2001. However, it was not widely utilized and accepted until 2003. CBCT captures data and constructs three-dimensional volumetric images. The constructed 3D image allows the clinician to view cross sectional images in 3 different planes: sagittal, coronal and axial. Due to the limitations of 2D radiography, utilizing a high-resolution 3D CBCT image for detection of vertical root fractures generated considerable interest. A CBCT image can be manipulated to view the tooth in a mesiodistal, buccal lingual or coronal apical direction, enabling the clinician to discern a fracture in these planes. Despite the advantage of constructing a three-dimensional image, the CBCT also has limitations. Spatial resolution is in the range of 2 lp/mm where conventional film and digital radiography averages 12-20 lp/mm, with lower resolution it may be more difficult to detect pathology (8). Artifacts such as beam hardening, streaking and cupping may limit the clinician’s ability to detect fractures (9). Metallic structures cause cupping, which misrepresents or distorts the actual anatomy. Streaking is a result of dark bands radiating from metallic objects, which hinders visualization of a pathologic condition in the area of diagnostic interest (9).

There have been multiple studies published which measure the size of fractures in extracted human teeth in an attempt to correlate fracture width with radiographic visualization.

These studies have utilized methodologies that include scanning electron microscopy (SEM), which measures and clarifies mode of fracture in extracted human teeth (10). Chavda and others utilized optical coherence tomography (OCT) to measure the widest part of a fracture to compare the diagnostic accuracy of digital radiography versus CBCT in the detection of vertical root fractures (11). Micro computed tomography (micro-CT) has also been utilized to analyze fractures in extracted human teeth (12).

The Hirox digital microscope has the ability to capture a real-time color image and produce a high-resolution two-dimensional image. Hirox microscopes have been utilized in several studies, across several disciplines, to include morphogenesis studies, measurements of cracks in steel box girders, and measurements of marginal and internal gaps in prosthesis (13, 14, 15). To date the Hirox digital microscope has not been employed to image fractures in extracted human teeth. Therefore, the purpose of this pilot study was to determine if a Hirox microscope system was a reliable method for measuring fractures in extracted human teeth and to determine the most optimal tooth and equipment positon.

II. MATERIALS AND METHODS

The Hirox model KH-7700 digital microscope consists of a monitor, computer processor, lens, platform, light source and camera (Figure 1). The Hirox digital microscope is a system that has the ability to capture real-time color images and produce high-resolution two-dimensional images immediately. Hirox samples do not need to be prepared with any special coatings, preserving the sample for future imaging if required. The Hirox system can also allow the investigator to take several measurements from one image. The sample consisted of five human teeth (3 mandibular and 2 maxillary). Three of the teeth had in vivo fractures and two teeth were cracked mechanically utilizing the method described by Monaghan et al. (16). A wedge was placed within 2-3 mm of the working length and hit lightly with a hammer until 1 mm short of the working length.

III. RESULTS

All teeth were individually positioned on wax and analyzed in a similar fashion using the Hirox 3D digital microscope (Figure 2). Each specimen was imaged using the KH-7700 Hirox digital microscope at 250x magnification utilizing the MXG-5040RZ high performance zoom lens. Based on Bornstein's methodology, three regions were imaged, coronal, middle, and apical (17). The most optimal microscope position to capture measurements of the tooth fracture was determined to be 5-15 degrees off the perpendicular axis (Figure 3). Lighting proved to be very important in obtaining the correct image. In addition to through lens lighting from the microscope an optical elements corporation additional light source was incorporated to enhance the ability to visualize the fracture (Figure 4). Figure 5 represents the optimum positioning of specimen, microscope, and supplemental lighting utilized in this study. The image in figure 6 is a representation of the image taken with the Hirox digital microscope. The light and dark colors in this fracture image are due to the two opposing light sources. A beam of light will continue to travel through a homogenous structure until it meets a fracture within the substance. This fracture creates a space, which directs the beam of light in a different direction. This results in a light and a dark area in the tooth separated by the fracture line. The light and dark areas define the fracture borders and support a more accurate measurement. Employing the line measurement tool in two-dimensions, three fracture widths were recorded in each region. The average of three measurements from each region was recorded, for a total of nine measurements per tooth. The data were evaluated using descriptive statistics. The results of the measurements according to sample number and region are listed along with the mean, median, maximum, minimum, and standard deviation (i.e. No1 was sample number 1 and region, c= coronal, m=medial, a=apical) (Table 1). This demonstrates how the data will be presented for the follow on study. As this is a pilot study to determine a methodology for fracture measurements, this is a representation of data collection.

IV. DISCUSSION

During the American Association of Endodontists meeting in 2015, Dr. Rob Roda stated that fractured teeth will be the new epidemic in dentistry. This is due to longevity of life and ability to maintain natural dentition longer, supporting an increase in the number of fractured teeth in the population. Fractures usually run in a facial to lingual plane (1). They can present as incomplete or complete fractures. Once diagnosed, extraction is the treatment of choice, replacing the edentulous area with fixed or removable bridge or an implant. The ability to accurately diagnose fractured teeth is critical to improving oral health.

This study elevated the feasibility of utilizing the Hirox digital microscope system to measure cracks in teeth at three different regions. The fracture measurements demonstrated variability in the size of cracks ranging from 10.66 to 179.90 microns, which confirms the ability of the Hirox to accurately measure small and large cracks in teeth. If the previously mentioned methodology is followed then measuring fractures in teeth can be expedited with accuracy. As stated previously, no study has analyzed fractures in extracted human teeth utilizing the Hirox digital microscope system. Benefits of utilizing this system include real time image acquisition, no requirement to specially prepare samples as with SEM, allowing the sample to be preserved for future studies, and no large scanning ranges to assess the entire fracture as is needed with OCT.

IV. CONCLUSIONS

This pilot study determined that the Hirox digital microscope system and software has the potential to reliably measure fractures in human extracted teeth. A follow on study will utilize this methodology to assess the relationship between fracture width and the ability to detect fractures using CBCT imaging.

FIGURES

Figure 1: Hirox KH-7700 Digital Microscope System

Figure 2: Extracted tooth and rope wax

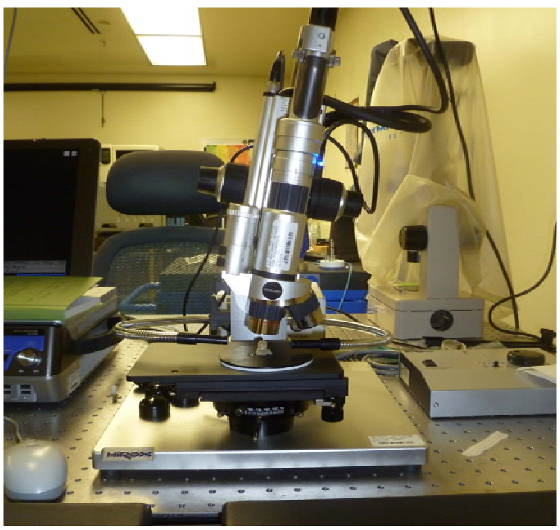

Figure 3: 5-15 degrees off perpendicular axis

Figure 4: OPELCO (optical Elements Corporation additional light source

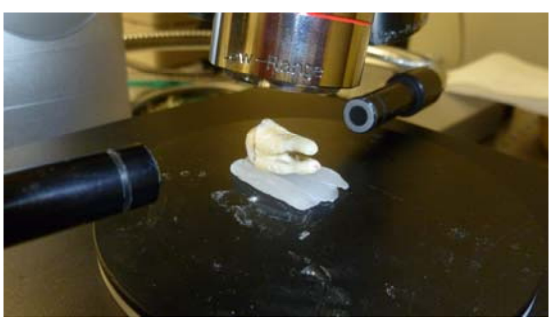

Figure 5: Measurement set up

Figure 6: Hirox Image at 200x

TABLES

Sample	Mean(μm)	Median(μm)	Max(μm)	Min(μm)	Stdev
No1c	20.84	20.76	24.69	17.07	3.81
No1m	30.78	30.78	41.50	20.07	10.72
No1a	38.00	40.56	42.53	30.90	6.22
No2c	174.63	173.90	179.90	170.10	4.94
No2m	129.03	128.00	139.30	119.80	9.79
No2a	88.24	90.86	92.71	81.14	6.22
No3c	69.27	68.29	85.00	54.53	15.26
No3m	45.92	46.35	52.72	38.68	7.03
No3a	23.81	23.36	27.25	20.81	3.24
No4c	157.60	159.33	173.62	139.84	16.96
No4m	145.43	158.92	168.64	108.73	32.15
No4a	56.37	48.29	76.41	44.42	17.46
No5c	32.39	27.17	43.01	27.00	9.19
No5m	17.84	21.40	21.45	10.66	6.22
No5a	20.84	20.76	24.69	17.07	3.81

*c=coronal m=middle a=apical

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